Yamato 793274, 981031

Anorthosite-bearing basaltic (polymict) regolith breccia
8.7, 186 g

Figure 1: Yamato 793274 and 981031 (images courtesy of NIPR).

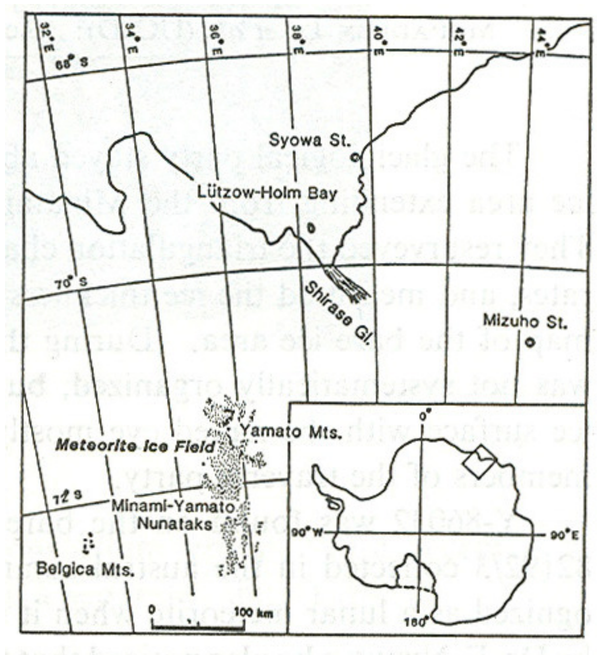
Introduction

Yamato 793274 (Fig. 1, 13) was found on bare ice near the Minami-Yamato Nunataks, by the JARE-20 meteorite search party January 3, 1980 (Fig. 2 and 3), 10 km SW of Yamato 793169. This 2.6 x 1.8 x 1.2 cm nearly complete stone was covered by a thin brownish to grayish dusty colored fusion crust (Fig. 1). Abundant, angular, white and black clasts (from a few to several mm in size) are set in a dark matrix. Yamato 981031 was found near Kurakake Nunatak of the Minami-Yamato Nunataks, during JARE-39 in the Yamato Mtns (Fig. 1,2,3 and 14). Because it is an anorthositic breccia, with a similar appearance to Yamato 793274 which was found nearby, it was thought to be paired (Kojima et al., 2000).

Petrography and Mineralogy

These meteorites are polymict breccias that contain numerous clasts and mineral fragments including basaltic, gabbroic, troctolitic, anorthositic, granulitic, and glassy lithic fragments, as well as pyroxene, olivine, plagioclase, glass spherules, FeNi metal, ilmenite, spinel, silica and barringerite (Fig. 4 and 5; Koeberl et al., 1991; Takeda et al., 1992; Takeda et al., 1991; Yanai and Kojima, 1991; Brandstatter et al., 1991). Although initially classified as an anorthositic regolith breccia (Yanai and Kojima, 1987), examination of additional sections revealed that there are more mafic minerals than plagioclase in the matrix fragments (Takeda et al., 1991; Yanai and Kojima, 1991). Total amount of highlands clasts estimated for Y-793274 is roughly 33% (Warren and Kallemeyn, 1991) compared to 10% for Y-981031 (Sugihara et al., 2004).

Compositional variation in the pyroxene fragments is large, from Mg# = 70 to close to zero (Fig. 6). Distinct pyroxene trends within several clasts have also been identified (Fig. 7; Arai et al., 1996). And, many of the pyroxenes in both clasts and fragments exhibit coarser exsolution lamellae than many other Apollo samples (Arai and Warren,



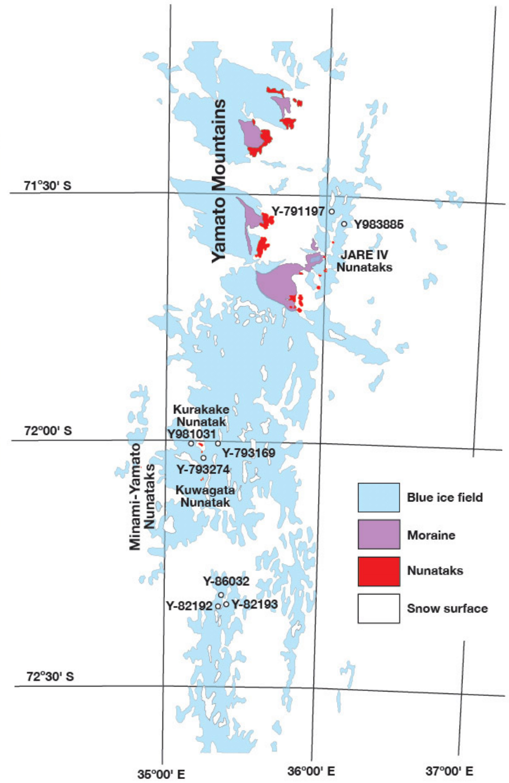


Figure 2: Location map for the Yamato Mountains.
Figure 3: Detailed location map for the Yamato lunar meteorites (map courtesy of the NIPR). Y793274 and 981031 are near the middle of the map.

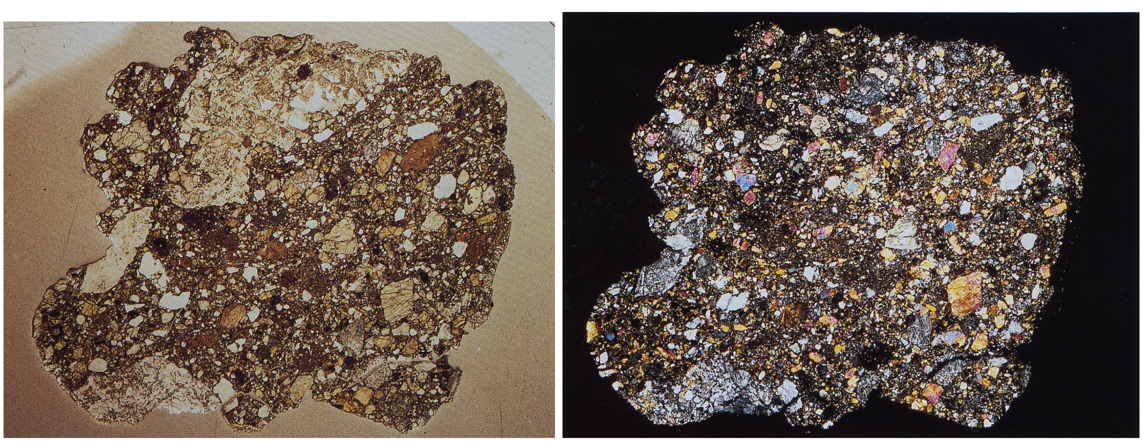


Figure 4: Plane polarized light and crossed polars views of thin section 91-1 of Yamato 793274 (from Yanai, 1987)

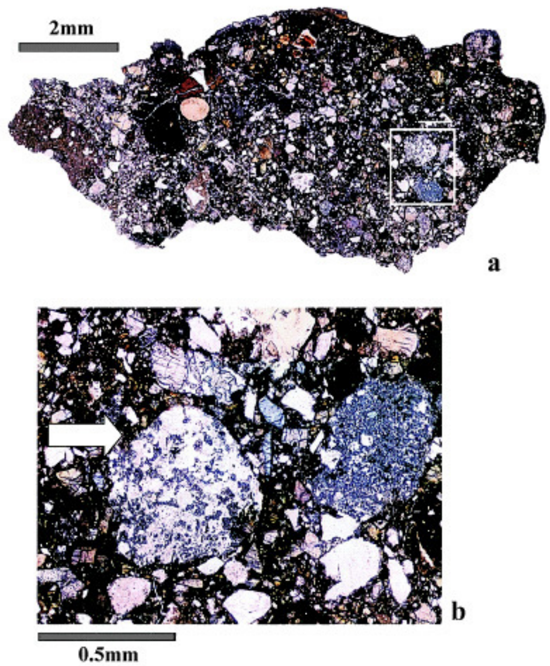
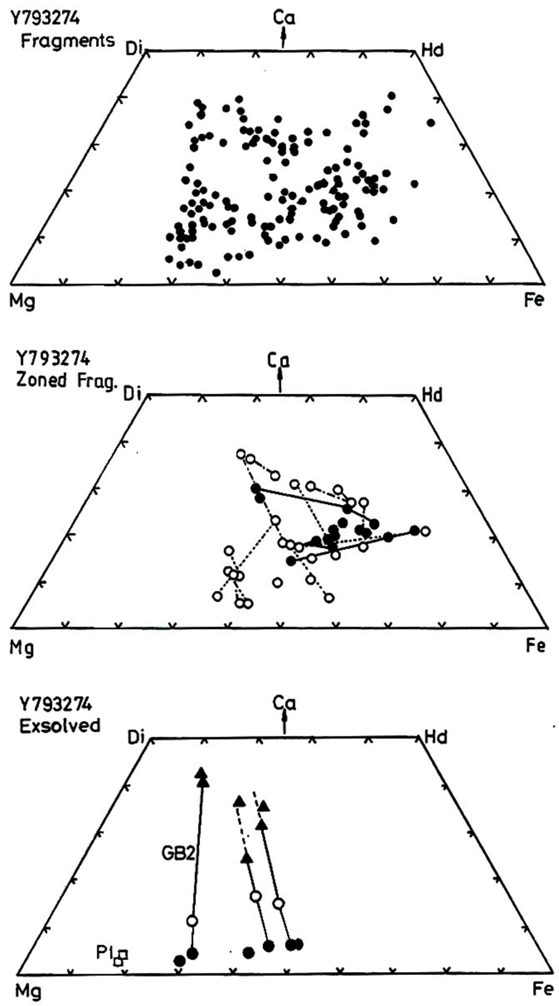


Figure 5: photomicrograph of section 53-6 of Yamato 981031 (from Sugihara et al., 2004)

1999), suggesting that these fragments may have originated in a plutonic setting, or from thicker lava flows (Takeda et al., 1992; Arai et al., 1996). Plagioclase feldspar compositional range from An_{85} to An_{100} (Fig. 8), with partial maskelynitization (Takeda et al. (1992). Olivine compositional range is also large from a grouping at Fo_{10} to one at $Fo_{55\text{-}80}$ (Fig. 8). The Fe-rich nature of the olivines and pyroxenes in mare clasts indicates that these lithologies are from a magmatic suite that underwent extensive fractionation.

Finally, the glasses in Yamato 793274 and 981031 exhibit a large compositional range, similar to that defined by QUE 94281. The similarity in textures and compositions led Arai and Warren (1999) to suggest these two meteorites are source crater paired. This will be discussed further below.



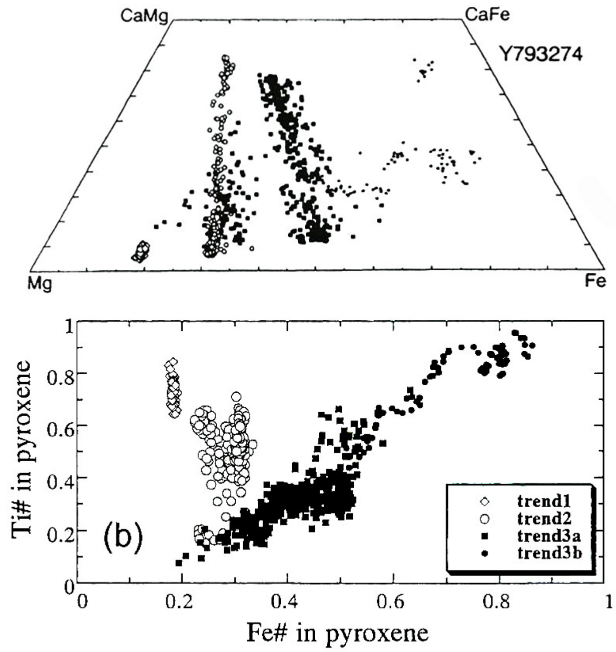


Figure 7: Pyroxene compositions measured by Arai et al. (1996) showing three distinct trends for different clasts.

← *Figure 6: Pyroxene compositions reported by Takeda et al. (1991) for fragments, zoned fragments and exsolved pyroxenes.*

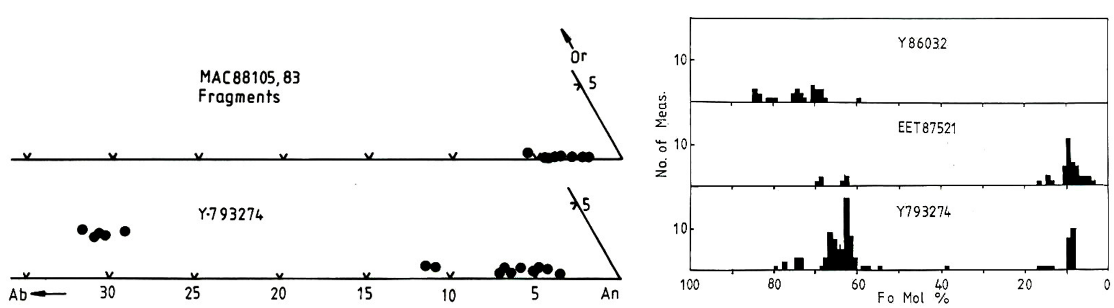


Figure 8: Feldspar and olivine compositions from Yamato 793274 (from Takeda et al., 1991).

Chemistry

Although such elemental characteristics such as TiO_2 content and Mg# would indicate an affinity with VLT basalt (Fig. 9), other elements such as FeO, Al_2O_3, and Sm show that Yamato 793274 and 981031 are truly intermediate between mare and highland end members (Table 1; Fig. 10; Warren and Kallemeyn, 1991; Karouji et al., 2002). A distinct link to VLT mare component was made by Warren and Kallemeyn (1991), based on Al-Ti correlations. The bulk, matrix and clasts from Y-793274 have similar REE patterns in terms of LREE enrichment, and Eu anomalies, to low TiO_2 basalts from Apollo 15 (Fig. 11). The presence of a KREEP component is possible given the factor of 4 or 5 enrichment in REE compared to KREEP-free samples, and the host phase may be glasses (Koeberl et al., 1991). High concentrations of Ni, Co, and Ir may be attributed to some meteoritic contamination (Lindstrom et al., 1991). And variation in the labile trace elements (e.g., Cd, Te, Zn, Sb) is thought to be due to volcanic processes rather than terrestrial weathering (Lindstrom et al., 1991).

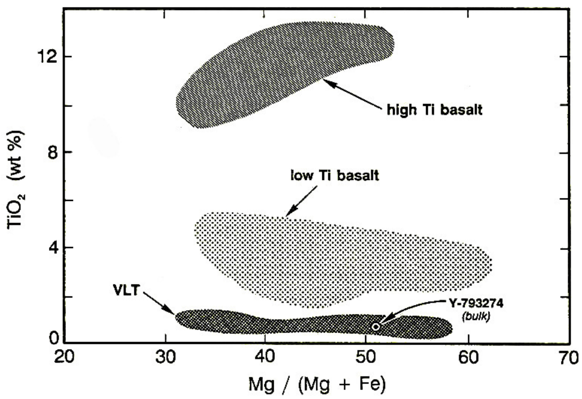


Figure 9: TiO_2 vs. Mg/(Mg+Fe) molar for Yamato 793274 compared to VLT, LT and HT basalt (from Koeberl et al., 1991).

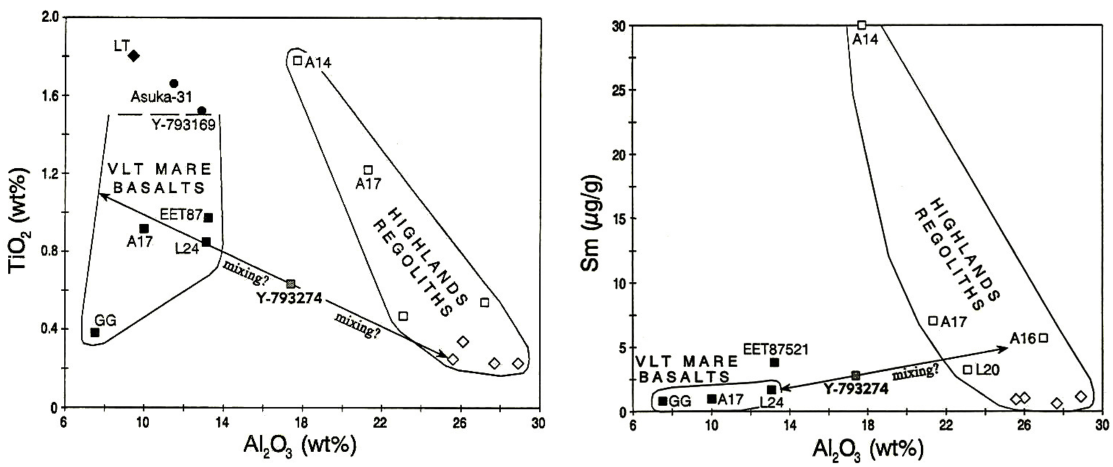


Figure 10: TiO_2 vs. Sm and TiO_2 vs. Al_2O_3 for Yamato 793274 illustrating the intermediate compositional features between mare basalts and highland regolith samples (from Warren and Kallemeyn, 1991).

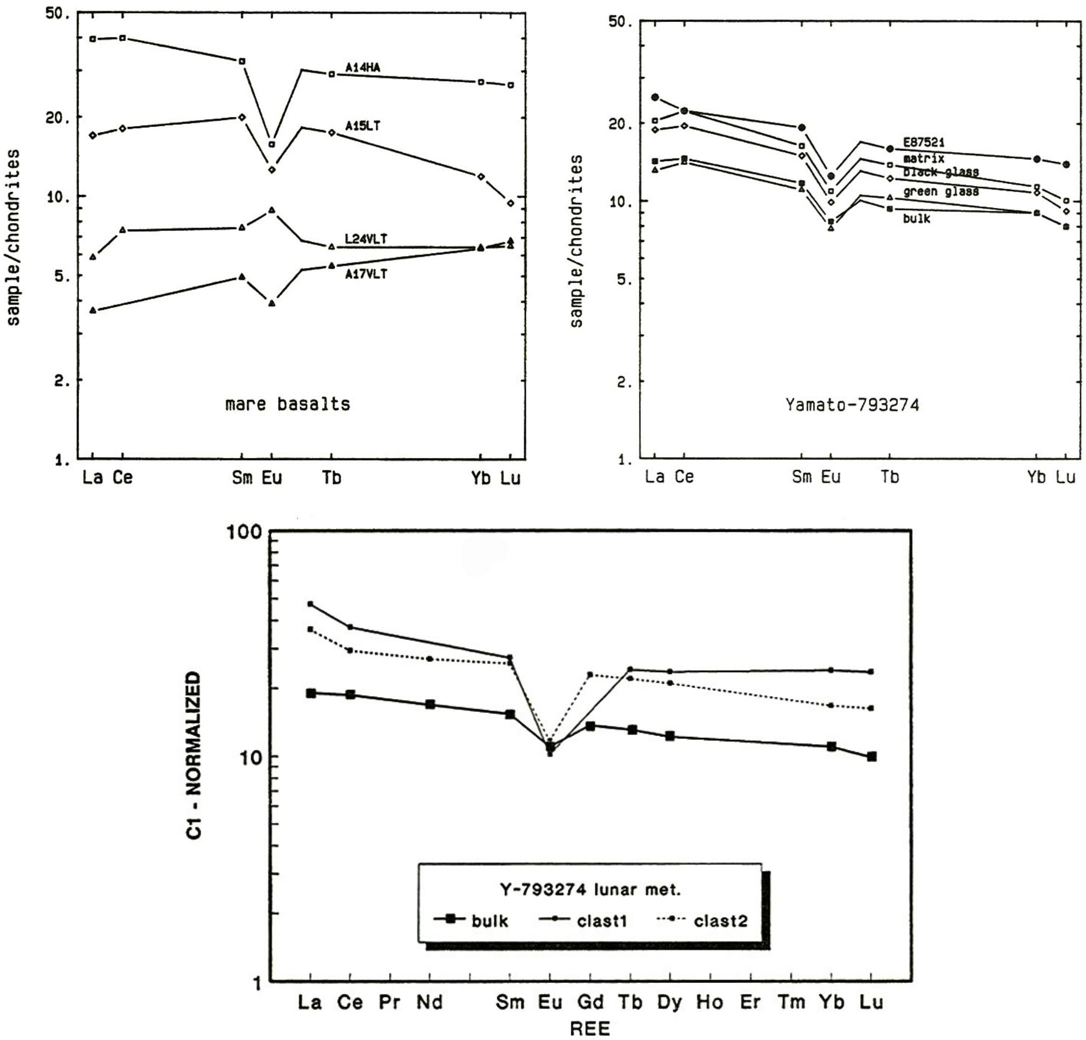


Figure 11: Rare Earth element diagrams for two different splits of Yamato 793274: top = Lindstrom et al. (1991); bottom = Koeberl et al. (1991).

Radiogenic age dating

Three anorthosite-rich clasts from Yamato 793274 were studied by bulk U-Th-Pb methods, and yielded ages at 4.0 and 4.41 Ga (Fig. 12). The interpretation of these results (assuming a μ value of 500) was that the anorthosite component formed early – 4.4 Ga, and was disturbed at 4.0 Ga by an impact event such as the terminal cataclysm. Additional work using the in situ analytical capability of the ion microprobe, yielded 3.5 Ga ages on mare affinity phosphates from Yamato 981031 (Terada et al., 2006). Clearly, additional constraints on the ages of mare and highlands components would be useful for these meteorites, but currently are consistent with ancient highlands materials mixed with younger mare materials.

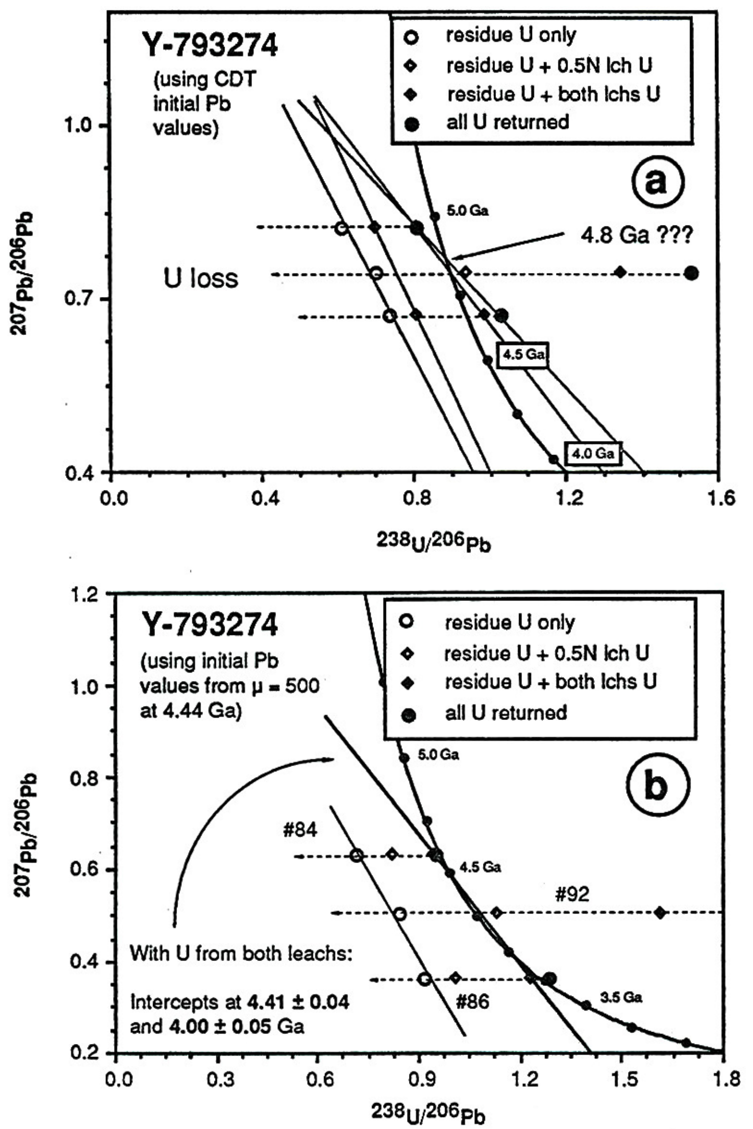


Figure 12: ^{207}Pb-^{238}Pb isochrons for Y-793274 showing intercepts at 4.0 and 4.41 Ga (from Tatsumoto and Premo, 1991).

Cosmogenic isotopes and exposure ages

Noble gas contents of both Yamato 793724 and 981031 are high, indicating derivation from a mature regolith (Eugster et al., 1992; Lorenzetti et al., 2003). Based on Ne, Ar, Kr and Xe isotopic measurements, Eugster et al. (1992) estimated a regolith exposure age of 700 200 Ma. A combination of approaches has produced the following history for Yamato 793274: ejection from Moon at 0.040 Ma (Nishiizumi et al., 1991b), with a very short Earth-Moon transfer time (< 0.12 Ma; Eugster et al., 1992: < 0.02 Ma, Nishiizumi et al., 1991a), and terrestrial age (0.020 Ma; Nishiizumi et al., 1991b).

Table 1a. Chemical composition of Yamato 793274 and 981031

reference	3	1	2	4	5	6	7	8
weight	43		28.88	51	254		241	177.4
method	c	a	c	c	b,c,d	e	c	c
SiO_2 %	47.06	45.67		48.30	45.46	44.88	46.421	
TiO_2	0.63	0.53		0.57	0.78	0.71	0.584	
Al_2O_3	17.38	16.73		13.70	17.31	18.44	17.322	
FeO	12.48	14.00	15.18	15.10	13.07	12.43	11.771	12.23
MnO	0.17	0.09	0.21	0.24	0.15	0.20	0.150	
MgO	8.96	9.52		9.00	9.30	9.42	8.458	
CaO	12.17	12.28	12.22	12.00	12.09	12.84	12.481	13.10
Na_2O	0.40	0.42	0.46	0.33	0.42	0.34	0.415	0.41
K_2O	0.11	0.08	0.07	0.06	0.07	0.04	0.072	
P_2O_5		0.08				0.13		
S %								
sum								
Sc ppm	28		31.7	37.8			26.4	25.1
V	83						72	
Cr	1960	1026	2010	2200	1779	1779	2645	4165
Co	43		41.4	41.1			39.7	39.8
Ni	122		100	70			159	150
Cu								
Zn	9.8		49	6.88				
Ga	4.8		4.04	4.9			3.9	
Ge	350							
As			0.053				<0.26	
Se	<1.7		0.28	0.304				
Rb			<2	0.322				
Sr	140		100	90			95	120
Y								
Zr	87		81	100			80	100
Nb								
Mo								
Ru								
Rh								
Pd ppb								
Ag ppb				8.8				
Cd ppb	<200			26.9				
In ppb				1.77				
Sn ppb								
Sb ppb			48	82			<100	
Te ppb				7.1				
Cs ppm	<0.21		0.1	0.0422			0.1	<0.15
Ba	85		97	58			101	81
La	6.7		7	4.68			7.7	6.8
Ce	15		17.9	12.6			19.1	18.8
Pr								

Nd	8.8		12				12.4	12
Sm	2.79		3.56	2.38			3.6	3.26
Eu	0.97		0.96	0.64			0.99	0.9
Gd			4.19					
Tb	0.61		0.76	0.48			0.77	0.67
Dy	4.2		4.64				5.3	
Ho							0.99	
Er								
Tm								
Yb	2.36		2.73	1.98			2.82	2.47
Lu	0.34		0.376	0.27			0.395	0.344
Hf	2.36		2.96	2			2.93	2.48
Ta	0.32		0.34	0.2			0.352	0.37
W ppb			190					
Re ppb	0.29							
Os ppb	0.0045							
Ir ppb	5.1		6.2	2.5			4.5	3.6
Pt ppb								
Au ppb	1.8		3	3.5			2.3	2
Th ppm	1.07		1.05	0.53			1.03	1.08
U ppm	0.23		0.26	0.19			0.19	0.3

technique (a) wet chemistry, (b) ICP-MS, (c) INAA, (d) PGA, (e) EMPA

Table 1b. Light and/or volatile elements for Yamato 793274 and 981031

Li ppm								
Be								
C								
S								
F ppm								
Cl								
Br	<1.5		0.21				2.2	
I								
Pb ppm								
Hg ppb								
Tl				4.54				
Bi				3.12				

References: 1) Yanai and Kojima (1991); 2) Koeberl et al. (1991); 3) Warren and Kallemeyn (1991); 4) Lindstrom et a. (1991); 5) Karouji et al. (2002); 6) Sugihara et al. (2004); 7) Warren et al. (2005); 8) Korotev et al. (2003)

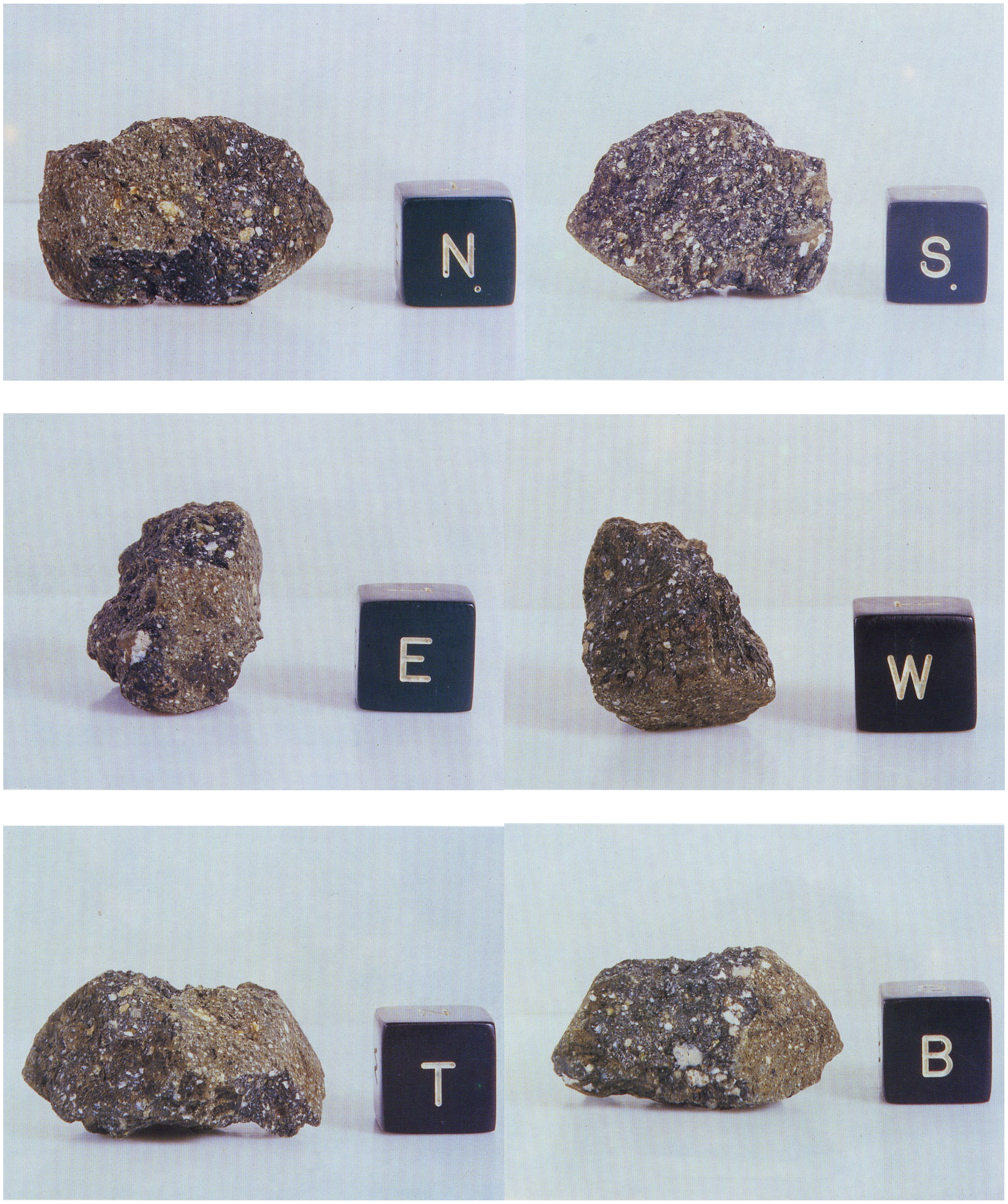


Figure 13: Six different views of Yamato 793274 before processing.

Figure 14: Six different views of Yamato 981031 before processing.